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AUTHOR Bird, Walter W.
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ABSTRACT

Air structures have developed through a number of significant stages: military applications, conventional standard air structures (the "bubbles"), exhibition structures, and permanent building applications. With no other type of structure is it possible to obtain clear, widespan coverage of almost unlimited areas, additional ceiling clearance for recreational activities at essentially no cost, translucency to permit uniform daylight, lighting through the entire roof system, and transportability or relocatability. Therefore, it is necessary to take into account the many features that are unique to the air-supported structure alone in evaluating competitive designs. If an optimum design for lowest cost is to be provided, and if the structures are to be successful, they must be of quality design; the design must fully coordinate methods of fabrication, handling, and shipment; and the installation procedures should be fully explored as part of the design with a fabricator experienced in working with large fabric structures. (Author/MLF)

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A NEW GENERATION OF AIR STRUCTURES

PRESENTED BY: Walter W. Bird, P.E.
President, Birdair Structures, Inc.

PRESENTED AT: The BRI National Technical Conference: AIR STRUCTURES IN EDUCATION
Antioch College Campus, Columbia, Maryland

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The other speakers this morning have described for you what I believe will prove to be a new generation of air structures. These are no longer dreams, but fast becoming realities. I am proud to have been associated with the LaVerne and Milligan College facilities which you have just seen, and with the development of the Santa Clara structure which we hope to be building later this year. We have worked hard to be sure that these are good structures as they are the "first of their kind." As Dick Theibert says, "While everyone is interested in air structures, they all want to be second." We now have some good "firsts" and hope that this will help insure acceptance of the fabric structure for permanent applications.

When I was asked to present a paper at this conference, it was suggested that as I had been associated with the design of the U.S. Pavilion and with the design and fabrication of LaVerne and Milligan, which are currently being built, and as I had been building air structures longer than anyone else, perhaps I could offer suggestions from my experience that would be helpful in insuring the success of new installations. If I can do anything to contribute to the success of new air structures, I'd like to do it. Nothing is more important at this stage in the development of this new industry.

STAGES IN DEVELOPMENT

I've been designing and building air structures for over 25 years. As I look back, I can see that the air structure has developed thru a number of significant stages. During each stage they've gained acceptance, but often for far different reasons:

1. Military applications. The first modern application of the air-supported principle was in our development of radomes to enclose large search radar installations which we started back in 1946. The Air Force had a problem and needed a solution. It imposed many critical design requirements, such as 125 mph wind velocities, heavy snowloads, transportability, ease of erection, etc. Wind tunnel tests were conducted and methods of analysis developed that made it possible to insure successful performance. The success of these developments has been dramatically demonstrated by the outstanding performance of the huge Telstar and other large radomes enclosing the antennas for the early satellite communications stations, our TPS-34 dual-wall radomes, large inflatable parabolic antennas, and other military structures which have now been in service ten years or more. These military

EA 005 538

applications were developed as they provided solutions to problems that could be solved in no other way. The Air Force was not concerned whether the structure would meet codes or requirements established for conventional structures, but only that they could do the job needed. However, these projects made it possible for us to demonstrate the feasibility and practicality of this uniquely new structural concept.

2. Conventional standard air structures (the "bubbles"). The success of military structures convinced me and my associates of the air structure's tremendous potential for commercial applications and in 1956 we formed Birdair Structures to introduce air structures for warehousing, pool enclosures, and other primarily portable or seasonal applications. Other companies soon entered the field. During this early period, emphasis was on low cost, not on aesthetics. Most commercial customers were looking for something to do a job cheaper. As competition increased, costs became even more important. New companies entering the field usually did so by cheapening their structures in order to reduce cost. There were no accepted quality standards and, not unexpectedly, this resulted in many poor quality structures and unsatisfactory performance. Marginal producers were soon out of business, but not before the industry's reputation had been hurt. Responsible fabricators banded together in an attempt to establish and maintain acceptable standards of performance. Improved designs were developed. However, many poor quality, sub-standard structures were built because the customers did not recognize the need for quality construction and bought on the basis of price alone. In spite of these problems, the air-supported structure continued to gain acceptance, principally for temporary or seasonal applications. Emphasis during this period, however, was on utility and cost, not on aesthetics. Few architects displayed any interest in the air structure at that time. While minimum standards had been established by the industry, as most of these structures were considered temporary, code requirements were not severely restrictive.

3. Exhibition structures. Throughout these early stages of development, architects were seldom involved in the program; they did not regard the air structure as a significant form of architecture. However, later in the second period, a number of architects with commissions to develop traveling shows or exhibits became interested in air structures because of their novelty. The unusual shapes and performance attracted attention--besides, they were relatively low in cost and relatively easy to transport. Being temporary in nature, the exhibit buildings were also not severely restricted by codes and variances could usually be obtained.

During this period, Birdair, as the originator and principal designer of air structures, had an opportunity to work with many creative architects in developing new and unique designs. This gave us an opportunity to demonstrate the versatility of air structures and the potential for many other

types of applications. During this period we were also very fortunate in having Dr. Gores, President of EFL, become interested in the possibility of air structures in connection with the need for low cost, adaptable facilities for educational purposes. He sponsored the installation of a small standard air structure for use as a gymnasium and indoor tennis facility at the Forman School in New England. We later enclosed the school's pool to provide a year-round facility. As you all know, Dr. Gores has been a strong advocate of the air structure for school use and his expressions, "scoop of sky" and "acre of June" aptly describe the potential of the air structure for "encapsulating space."

4. Permanent building applications. I believe we are now just entering into the fourth and most important stage of the development of air-supported structures. While standard air structures, mostly portable installations for seasonal applications, are still a major part of the industry's work, the air structure is no longer regarded as a novelty, but is being accepted as a candidate for permanent structures. But now it must stand on its own merits in competition with conventional structures. It is being recognized as not just another type of roof, but as a uniquely different type of structure with characteristics and capabilities not possessed by any other building form. One of the earlier speakers contended that fabric structures must be regarded as temporary because of their relatively short life. He also implied that, because of the high cost of our newest, potentially longest life material (Teflon-glass), they also offered no cost advantage. This is far from the case. The Telstar dome built over ten years ago is still in service and with proper maintenance is expected to last another ten years or more. While unsupported vinyl film, such as was used in the experimental Antioch structure here in Columbia, has a life expectancy of only 2-3 years, the relatively low cost, vinyl-coated fabrics conventionally used will provide 5-8 years or more of service and with new top coatings an even longer service life is anticipated. Based on outdoor exposure and accelerated weathering tests, Teflon glass is expected to provide a service life of 20 years or more. We can provide long life with fabrics where warranted, but, where initial cost and obsolesence may be a governing factor, can provide good structures at lower cost. The proper selection of materials is an important factor in designing air structures for new applications. The air-supported structure has thus been shown to be a good candidate for permanent building applications, if properly designed, but it must stand on its own merits in competition with conventional structures.

As I have pointed out, cost alone is not a satisfactory way of evaluating the use of air structures as compared to conventional structures. With no other type of structure is it possible to obtain clear, widespan coverage of almost unlimited areas, additional ceiling clearance for recreational activities at essentially no cost, translucency to permit uniform daylight lighting through the entire roof system, transportability or relocatability, if desired, and many other features that are unique to the air-supported structure alone. A good knowledge of air structures is therefore essential in evaluating competitive designs.

Where air structures are used as permanent buildings, we are still faced with the problem that most code requirements were established based on conventional construction, and have little or no significance when applied to air structures. We can show where an air-supported structure, because of its low mass, self-venting characteristics in case of a severe fire, and pressure differential maintained across the surface of the envelope, is far safer than many conventional buildings even when fabricated from materials that are not classed as fire resistant. However, new materials such as the Teflon glass, which can be classed as non-combustible and will meet most of the required fire tests, permit us to use the air structure for applications even under present generally inapplicable code requirements.

CONSOLIDATING OUR GAIN

We have worked hard to show that air structures can play an important role in new construction. The success of many outstanding military and commercial installations and, in particular, the success of the first large cabled roof on the U.S. Pavilion at EXPO '70, have gained acceptance for air structures for permanent applications. I believe that the most important thing we can do now to consolidate our gain is to be sure that each new application is successful. Experimental structures serve a very useful purpose in helping us all to gain experience and especially in helping our young architects to learn by their experience in building experimental structures. Polyethylene film, which is widely used by architectual students, is cheap and meets their needs. Other unsupported films which have limited life are suitable for some applications, but it is important to the acceptance of air structures that such applications be recognized as experimental or temporary and that proven materials and proven techniques of fabrication be used on projects offered to the public. This same philosophy applies to designs.

COORDINATE DESIGN

I believe it is significant that the majority of successful air structures have been developed as an extension of proven principles of design by experienced fabricators. While we should encourage experimentation with new shapes, these should be first proven by actual experimental use before being used on public buildings where poor performance could do irreparable damage to the industry. We cannot afford to experiment on the public. The large number of "cheapies"--air structures fabricated from unsupported films and used as private pool enclosures and other marginal units put on the market--have resulted in public concern as to the acceptability of air structures for permanent applications. Let's not cut corners or compromise our designs now; let's establish the reputation of the air structure with good design and quality construction.

As the first company in this new field, Birdair has had the opportunity of working closely with many architects in developing unusual and exiting designs:

1959 Carl Koch-Paul Weidliner - Bostor Arts Center Theater
1960 Victor Lundy - "Atoms for Peace" Traveling Exhibit
1962 Strickland, Brigham & Eldredge - Central American "Atoms for Peace" Exhibit
1964 Victor Lundy - New York World's Fair, Brass Rail Exhibit
1964 Reino Aarnio - New York World's Fair, Hawaiian Village structures
1964 Eggers & Higgins - New York World's Fair, Schaefer Pavilion roofs
1967 Fairfield & DuBois - Ontario Pavilion EXPO '67 (tensioned fabric)
1969 Perkins & Will - The Hommocks School retractable roof
1970 Davis & Brody-David Geiger - U.S. Pavilion EXPO '70 Japan
1972 Shaver Partnership - LaVerne College and Milligan College Student Centers
1973 Albert A. Hoover & Associates - Santa Clara College Student Center

A number of these structures are shown in the illustrations.

In looking back over these outstanding projects which were all the first of their kind, I feel that much of the success can be attributed to the opportunity to work closely with the architect from the original concept. In normal construction practice, the fabricator is seldom chosen before the design is developed and can therefore contribute little to affect economies in construction. However, the air-supported structure is a uniquely different type of structure. Different not only in concept, but in the type of materials, method of fabrication, and methods of installation. The cost of fabrication can be greatly influenced by the techniques needed to fabricate, ship, and install the structures. If an optimum design for lowest cost is to be provided, it is important that an experienced fabricator, fully familiar with all aspects of air structures, be involved in the early design.

However, this often is not possible on public buildings where competitive bidding, based on completed drawings, is required. On such programs I believe it is imperative that the architect obtain the services of an engineer experienced in design and fabrication techniques. There have been too many cases where the architect relied on misinformation obtained from a variety of sources in developing a design, only to find that it was impractical and that a costly redesign was necessary. Many potentially good projects have been abandoned because of poor conceptual designs that could not be supported by available materials or fabrication techniques. In order to avoid this situation, most of the fabricators will be glad to review the architect's preliminary design and offer suggestions. Because of demands on our time, however, only a limited amount of free service can be offered. However, those of us who can offer professional engineering services, as Birdair, will be glad to work with the architect or engineer on a consulting basis in developing designs and specifications for the air structure and all related equipment. The relatively small added cost will normally help greatly in assuring a successful program. We served as consultants on the design of the U.S. Pavilion, though fabrication was carried out in Japan. Where possible,

your fabricator should be selected early in the program so that he can contribute to the detail design. We must all work together as a team in order to take full advantage of all of the experience available in order to assure successful performance. This is the best way to assure acceptance of the air-supported concept and success for the new generation of air structures.

IMPORTANT ELEMENTS FOR SUCCESS

Design

Quality design is essential to the success of an air structure. There is no such thing as a good, cheap air structure. It may be good, or it may be cheap, but not both. However, a good air structure can be economically designed without sacrificing quality.

There is a misconception among many architects and engineers that fabric structures are inherently low in cost. We are frequently faced with the problem that people talk in terms of $2-3 per sq. ft. The low cost of conventional, standard air structures is possible only because of standard designs, standard patterning, and production fabrication procedures. If you are seeking a custom design with special patterning and special features, be prepared to pay for the extra engineering costs and the much higher cost of fabrication involved in special patterning and special handling. If you are considering the use of new exotic shapes, recognize the problems that are involved. As Vic Lundy remarked, the air structure has a mind of its own. Remember that every point on the surface of an air structure must be in equilibrium. Aerodynamic loads, not the inflation pressure loads, result in maximum loading. Too often study programs on unusual shapes consider only the uniform loading applied by inflation pressure. Load and stress distribution on exotic shapes are difficult to determine but must be fully considered if you are to avoid stress concentrations. The advantage of cable reinforcing is that it reduces the size of individual elements, thus helping to hold stress levels within reasonable limits. Birdair has developed a number of unique cabled designs which permit controlled distribution of load and greatly increased factors of safety. Birdair's CABLEDOME™ design, which provides a network of triangular elements, pretensioned by inflation pressure to provide a space frame which can carry compressive loads as a relaxation of tension, we believe provides the ultimate in structural strength and stability. In evaluating your design for an air structure, do not fail to recognize and take into consideration the special requirements for access. Because of the pressure differential maintained within the structure, revolving doors or special pressure-balanced, outward-opening doors are required. The need for this special type of equipment has not even been mentioned in the Conference to date, but proper selection and design of these facilities is essential to successful performance.

Fabrication

Costs are greatly influenced by the design. If methods of fabrication are not fully considered, the cost of handling and fabrication can be excessive. Fabrication techniques must be closely tied in with the fabricator's equipment, because special, and sometimes proprietary, equipment has often been developed in order to achieve quality fabrication at lowest cost. The advantage of the air structure lies in its being able to be fabricated in the shop. Complete structures or major elements can be built and, as they can normally be readily folded, can be transported to the site at low cost. By keeping field labor costs to a minimum, costly field labor expenses can be saved. It is therefore important that the design fully coordinate methods of fabrication, handling, and shipment.

Installation

One of the major cost savings with air-supported structures is in field installation. By designing so that complete roof systems or major elements are assembled in the factory, the high cost of field labor under uncertain weather conditions can be avoided. However, the conventional construction contractor cannot normally help much in developing techniques of installation as he seldom has experience in working with fabric. One of the problems often overlooked is the vulnerability of fabric structures to damage due to wind loads while they are being put in place--before attachment and tensioning. Installation procedures should therefore be developed to keep the time required for installation to a minimum. Therefore, in order to realize maximum cost savings for the installation, it is essential that installation procedures be fully explored as part of the design with a fabricator experienced in working with large fabric structures.

AN EXCITING NEW PROJECT

A number of you have questioned me about a recent release which has been circulating around the Conference reporting Birdair's participation in the design and fabrication of a 1400 ft. diameter air-supported structure to serve as an enclosure for Odyssey 2000, a theme park scheduled to be built in the Indianapolis area next year. The developer selected Birdair's CABLEDOME™ design for this project. The "CABLEDOME" design offers outstanding stability and safety.

Their need on this project was to provide an environmental enclosure for the park which would permit year-round use. A feeling of openness with good daylight lighting was desired. There is no intention of trying to maintain uniform indoor temperatures year round, but a need to provide a protective environment in which the public could participate and enjoy the activities offered throughout the year. In addition to reduced costs of environmental control--costs which become prohibitive on large conventional structures--we believe there is another advantage to this approach. The temperature within the enclosure will be maintained close to prevailing outside temperatures throughout the year. Comfortable conditions will be assured by providing protection from the direct rays of the sun, from the wind, and from the rain or snow, while maintaining temperatures appropriate to the season. Individual buildings within the enclosure will be heated or air conditioned when appropriate to assure maximum comfort for the particular activities involved.

Our experience has indicated that with translucency selected to reflect a large part of the solar heat load and with controlled ventilation, comfortable conditions can be maintained with our large air structures without resorting to a heavy air conditioning load. I was interested in hearing the previous speaker, Dr. Geiger, present information based on a study which had been funded by EFL which confirmed our experience.

We are naturally most enthusiastic about the prospect of building this large air structure, which to our knowledge will have the largest clear span in the world. We will be working closely with the architects, our suppliers, and with other engineers to help assure an optimum design. By being responsible for design and fabrication of the roof structure, we will be able to assure a successful design. The success of this application should do much to help promote the acceptance of air structures for large enviornmental enclosures for which they are so well suited. We expect this to be an outstanding example of the "New Generation of Air Structures."